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Ford Motor Company's Investment Efficiency Initiative: A Case Study

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Preface

This document was prepared for the Office of the Principal Deputy Under Secretary of Defense (Acquisition and Technology) under the task order Defense Manufacturing Strategy, and addresses a task objective, to provide a case study on integrated product/process development implementation. This case study will be used for acquisition and technology training purposes by the sponsor. Many of the incentives, strategies, and implementation approaches at Ford have parallels in and implications for the acquisition processes of the Department of Defense (DoD). The DoD student is asked to draw conclusions based on his or her own situation.

The authors wish to thank the Ford managers who participated in this study: Mr. Gene Nelson, Ford Director, Advanced Manufacturing Pre-Program Engineering, and Ms. Gail Copple, Ford Investment Efficiency Manager. We are grateful to Mr. Barry Lerner, author of related Ford training materials, who clarified many points for us. We also thank Dr. Daniel Whitney, Senior Research Scientist at the Massachusetts Institute of Technology's Center for Technology, Policy, and Industrial Development; and Mr. Russell Shorey, consultant, for their many helpful suggestions and reviews.

This document was reviewed by Dr. Richard J. Ivanetich of the Institute for Defense Analyses.

This study was conducted during 1996–1997. Ford released the information for public distribution after two years had elapsed.

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Executive Summary

Ford Motor Company operates in an intense competitive environment. Its traditional markets are now mature and show only marginal growth. Four incentives are driving Ford: emergence of new growth markets, smaller-volume niche markets, shareholder returns, and competitive drivers. Growth markets for the auto industry are centered in the Far East, Eastern Europe, and South America. To compete effectively in the next century, automotive companies must leverage their resources to grow their businesses profitably in these markets.

This is why Ford and the major automakers place such an importance on *Investment Efficiency* as a key operating strategy. Investment Efficiency is the ability to simultaneously minimize investment and optimize value for the customer—the goal being to provide the most product for the investment dollar. Ford has developed its own process of Investment Efficiency, centering on improving the compatibility between its product assumptions and its existing manufacturing processes. This process, Product and Process Compatibility, is facilitated by improved communication of product engineering and manufacturing very early in and throughout the product development process. Investment Efficiency through Product and Process Compatibility addresses the problem of getting development and production costs under control both on individual projects and across projects.

Critical aspects of the Product and Process Compatibility approach to Investment Efficiency include organizational and technical implementations:

- **Organizational implementation.** Upper management has focused on an implementation strategy based on detailed design-production interrelationships and has enforced the use of this strategy. Ford has formed two new groups of experts who have a comprehensive understanding of how manufacturing processes are related to and affected by designs and of the investment implications of manufacturing processes. These groups work with the design and engineering teams on a car project from its earliest stages.
- **Technical implementation.** At a technical level, the manufacturing and investment knowledge is captured by design metrics, quantitative targets, and

design rules to be used during the integrated engineering process and at milestone reviews.

In discussions with the authors, Ford managers also provided the following "lessons learned":

- **Changing mind-sets.** The Investment Efficiency process required a fundamental change in the mind-set for Ford's product development organization. Because this mind-set is the result of many years of vehicle development, the change in the culture does not occur overnight. Change will be gradual rather than immediate.

- **Understanding the need for change.** Ford's own financial studies showed Ford lagging behind competitors in product development costs. Entering overseas markets required Ford's products to be low cost but still provide outstanding quality and exciting features. At the same time, the mature markets required the introduction of new and innovative products. Thus, the need for Investment Efficiency was clear to both Ford management and its employees.

- **Strengthening management support.** In establishing the Investment Efficiency Council to oversee the development of process and review progress with the platform teams, Ford signaled its senior management support to its employees. No platform team can go through the development "gateway," Ford's product milestone review, with an investment status not at or near its investment target.

- **Creating aligned objectives.** Ford is breaking down organizational "chimneys" through the use of matrix management. Ford is also using the Affordable Business Structure, a planning framework for costs that guides development of vehicles that are both affordable to Ford and its customers. The Affordable Business Structure targets are the common element to align the business objectives of manufacturing divisions and the product development groups. Each organization is charged with getting its cost on target with the Affordable Business Structure.

1. Introduction

This document describes how the Ford Motor Company is implementing a management-driven initiative to drive cost tradeoffs and cost targeting very early in its product/process development process and throughout product realization. The name of this initiative is *Investment Efficiency*—the ability simultaneously to minimize investment by Ford and to optimize value for the customer. The goal is to provide the most product for the investment dollar. Implementation of the initiative is through the mechanism called Product and Process Compatibility.

As a case study, this document is intended for use by students of the acquisition process in the Department of Defense (DoD). It is intended to elicit thought and discussion of how the Department can better integrate cost tradeoffs and cost targeting into its acquisition processes and integrated process teams.

The contents of the document are based on two visits to Ford during 1995, updates and revisions to the document from Ford management during late 1996, and studies, contacts, and documents going back several years by the authors and others. The authors used this broad base of experience to place the activities in a historical context. Quantitative results are estimates by the Ford managers interviewed for the study or from previously published studies. Although the reported data were not independently verified, these stories have been subjected to the scrutiny and judgment of the authors and reviewers.

Organization of this document

Chapter 2, "The Need for Investment Efficiency at Ford," discusses the four incentives that drove Ford to Investment Efficiency: emergence of new growth markets, smaller-volume niche markets, shareholder returns, and competitive drivers.

Chapter 3, "The Investment Efficiency Process," gives a brief background on Investment Efficiency at Ford before the Ford 2000 reorganization began. It then defines and describes what Investment Efficiency is today at Ford.

Chapter 4, "Basic Targets of Investment Efficiency at Ford," compares previous and current methods of costing products.

Chapter 5, "Strategies of Investment Efficiency," describes the strategies that led up to and now include Product and Process Compatibility, a strategy of arriving at the best product and process concept by simultaneously optimizing four main drivers of investment: Reusability, Commonality, Carryover Product, and Complexity Reduction.

Chapter 6, "Product and Process Compatibility Tools," discusses Investment Efficiency Metrics, Manufacturing Design Rules, Generic Product/Process Concepts, and Life Cycle Cost Analysis—all used to drive Product and Process Compatibility.

Chapter 7, "Future Small Car Program Pilot," contains a description of a pilot program using Ford's Investment Efficiency initiative.

Chapter 8, "Organizational Changes at Ford," describes the changes in management and in Ford's relationship with its suppliers.

Chapter 9, "Lessons Learned," is a compilation of lessons reported by Ford managers. These lessons are grouped into four areas: changing mind-sets, understanding the need for change, strengthening management support, and creating aligned objectives.

Chapter 10, "Discussion Items," lists issues and questions pertinent to students of the DoD acquisition process.

At the end of the document, a bibliography, a glossary, and an acronym list are given. Appendix A presents discussion ideas to further explore the concepts presented in this paper. These discussion ideas can be used with students in a classroom or interactive setting.

2. The Need for Investment Efficiency at Ford

Ford is a very large, U.S.-based international manufacturer of cars and trucks. It is one of a few dominant companies in its industry. Until the early 1980s, Ford and its domestic competitors had little serious competition from abroad. But the expansion of international companies into U.S. markets, in combination with other external events, created radical shifts in consumer options and preferences. In the United States, government became more involved in consumer protection and industry regulation. These shifts shocked the domestic automobile industry from a position of market leadership to one in which growth, sales, and profitability were severely challenged.

During the period of the mid-1980s through late 1996, Ford has increasingly broadened the scope of its initiatives to address these challenges. First there was a concentration on improving quality. Then Ford mounted the effort to integrate product engineering and manufacturing process design during the engineering phase. Also during the period, Ford adopted and developed ways of improving its approach to defining product requirements from the customer's viewpoint, and it began a revolutionary shift in how it dealt with suppliers as team members rather than adversaries. During the 1990s, Ford began to implement very broad, systematic approaches to cost savings in the Product Development process and to institutionalize the process.

During the early part of this decade, it became apparent to top Ford management that its product development costs were not competitive with the best in the industry. In addition, the automotive industry landscape was changing rapidly, driven by the emergence of new markets. Four incentives drove Ford to Investment Efficiency: emergence of new growth markets, smaller-volume niche markets, shareholder returns, and competitive drivers. Each incentive is discussed in further detail in the following subsections.

2.1 New Growth Markets

Beginning in the 1980s, the world's major automakers realized that the growth rate in its traditional markets (North America, Europe) had slowed rapidly. These markets were saturated with overcapacity, and future growth in these markets was determined to be minimal.

However, the late 1980s saw political upheaval around the globe, with new democracies being born around the globe. Suddenly, new markets for the automotive industry were appearing on the landscape: the Far East, South America, and Eastern Europe. Ford and the other major automakers realized that these markets were the areas of future growth. Now the challenge to Ford—and to most automakers—is how to develop low-cost vehicles based on low product investment. Cost is a major barrier for consumers in those markets.

2.2 Smaller-Volume Niche Markets

The small amount of growth in the mature markets interacts with the customers' interest in products that result only in the creation of niche segments. Today's automotive customer is demanding more niche products. Many of these niche markets are for vehicles produced in relatively small volumes. Ford had to develop a process that would allow it to produce vehicle products in small numbers with efficient investment levels to realize a profit.

2.3 Shareholders Returns

The ultimate incentive for Ford as a corporation is to produce an attractive return to its shareholders. Ford's ability to generate profit from its automotive business is the basis by which it can reward its shareholders with increased dividends.

2.4 Competitive Drivers

All the world's major automakers are seeking to reduce their cost base and to improve value to the consumer. In the 1980s, quality served to be the competitive advantage for automakers. Those automakers with high quality products were able to gain market share by providing consumers with reliable vehicles. By the 1990s, the quality gap between the major automakers had narrowed, and customers expected high quality as a "given" when they purchased a vehicle.

Now the major competitive advantage of the 1990s is *cost* and *value* to the customer. Companies that can give the consumer the most product for the transaction price provide the ultimate value. The major automakers are streamlining their organizations and product development processes to squeeze costs out of their systems. They have learned that costs can be streamlined out of their product development systems by reducing product-related investment. This is being accomplished by reducing vehicle complexity and uniqueness, sharing components across models, carrying over commodity-

type parts that provide little or no differentiation to the consumer, and designing new products that reuse manufacturing equipment and processes. *Specific examples:*

Toyota has led the effort in investment efficiency actions:

- The new Corona and Carina models share parts.
- RAV4 shares 40% of its key parts with other Toyota products.
- Model variations have been reduced by 30%.
- The number of key parts has been reduced by 40%.
- New models target 70% in carryover parts.

Nissan has also set aggressive targets for investment efficiency:

- A committee has been established for model and parts reduction.
- The number of chassis types was reduced from twenty to fourteen, with an estimated savings of $1 billion.
- The number of platforms has been targeted to be reduced from thirteen to six or seven by the year 2000, with an estimated savings of $2 billion.
- The number of parts has been reduced by 50%.
- The number of model variations has been reduced by 30%.
- Parts commonality is now 60%.
- The Laurel sedan has 20% fewer parts than the previous model and it shares 50% of its parts.
- The Largo minivan shares 45% of its parts.

General Motors is also aggressively employing investment efficiency actions in its product development process. Specific reductions include the following:

- Total number of car platforms from twelve to five
- 9 engine families to 5
- 10 air conditioning types to 6
- 6 steering column groups to one
- 32 seat types to 4
- 24 starters to 10
- 12 batteries to 5
- 2,700 electrical connectors to 750
- One-third reduction in panels per car

The General Motors *1993 Annual Report* states that "cost savings and efficiencies...are enormous." It predicts "further economies of scale...as we decrease...vehicle architectures and increase production volume."

The published results of the streamlining efforts of these three automakers alone indicate the broadness of these activities. They range from mandating a common assembly architecture for cowl and dash joint structures to reductions in model variations and in the number of key parts.

Achieving the objectives cited will neither affect product performance nor reduce customer expectations. Rather, these objectives emphasize the historical imperative of industrial management who had tried for decades to focus design activities on product design features that were unique as far as the customer is concerned while minimizing the resources expended on the non-unique features. For example, industrial management experts have questioned having nine engine families, forty different electronic key fobs, or twenty-one different radiator caps where a few might do just as well. It could also be argued that all these items are mature technologies so one is no better than another. Why then have nine engine families when five will provide the performance differentiation needed in the market place?

3. The Investment Efficiency Process

3.1 Introduction

Cars are complex. They consist of several subsystems, each requiring substantial development and manufacturing investment. In 1980, Ford took up to sixty months to develop a new model. Powertrain programs (Engines/Transmissions) took up to seventy-two months. Studies have shown that the average development in the U.S. car industry in the 1970s and early 1980s took substantially longer than that of the Japanese. During this time, the resulting U.S. products were viewed as deficient to the imports in overall product quality.

The manufacturing and final assembly facility for a product in the automotive industry takes up more than 600,000 to one million square feet, not counting facilities in the supplier chain. Each semi-customizable product is produced in quantities that exceed that of typical defense systems by a great deal, but many of the management lessons learned by Ford are applicable in the defense context

Ford buys materials, assemblies, and subsystems from internal divisions and a large supplier network. Suppliers range in size from small machine shops to full-service suppliers, responsible for designing, engineering, and production of vehicle systems. As full-service supplier relationships were developed, Ford found it necessary to have computer-based information design systems for both business and engineering purposes.

Generating a product as complex as an automobile is a time-consuming task. There are milestones or "gateways" where program reviews are held and product/process plans are measured on the basis of product features versus costs to achieve.

Over the years, the auto companies have tried to achieve Investment Efficiency with arbitrarily set cost targets and no real control mechanisms. Ford has found at critical review points (about forty-one months prior to large-scale production) that typical programs' projected costs were two to three times more than the costs that were affordable to Ford and the customer; this phenomenon occurred irrespective of program size. The program teams would then spend the next several months scrambling to change product assumptions and features to drive down to their investment targets. This process of

"thrifting" the product (removing features and options) wasted engineering resources, risked product development timing, and had an adverse effect on quality. In addition, this process did not guarantee efficiency because it only focused on driving an in-process design down to a cost target.

3.2 The Ford Product Development System (FPDS)

In January 1995, the "Ford 2000" reorganization was launched to improve all of Ford's practices. The Ford Product Development System (FPDS) was created as part of Ford 2000 and established to re-engineer the Product Development System. FPDS is a cross-functional process that involves all Ford activities and suppliers. As with similar initiatives in other companies, it seeks to improve quality, cost, and time to market.

In addition to engineering and cost improvement, Ford has focused on other enablers to achieve significant improvements in quality and cost under FPDS. One of the more significant enabling tools is the incorporation of new computer-assisted design/manufacturing/engineering (CAD/CAM/CAE) processes within Ford, which are linked to its suppliers.

3.3 Investment Efficiency Goals

Investment Efficiency is a subprocess of FPDS and is the ability to minimize investment and optimize value for the customer simultaneously. The goal of Investment Efficiency is to provide the most valuable product for the investment dollar.

Figure 3-1 is the way Ford depicts the projection of total project cost at various times during the life of a development project. The top curve is what Ford has typically experienced in the past. The bottom curve is for the process resulting from current initiatives.

The goal of Ford's Investment Efficiency process is to control the development of product assumptions earlier in the development process. As shown in Figure 3-1, at the critical review points prior to approval of the project, the team's status must be within 20% of its affordable cost target.

Figure 3-2 is Ford's depiction of the drivers necessary for the new process to converge to affordability faster and better than the old process.

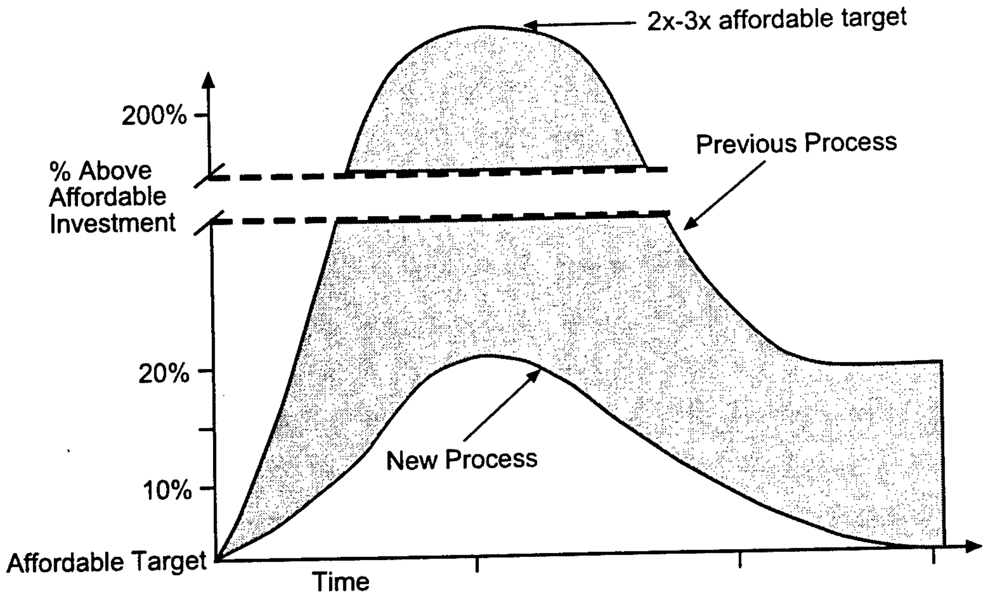

Figure 3-1. Project Cost Projections Over Time

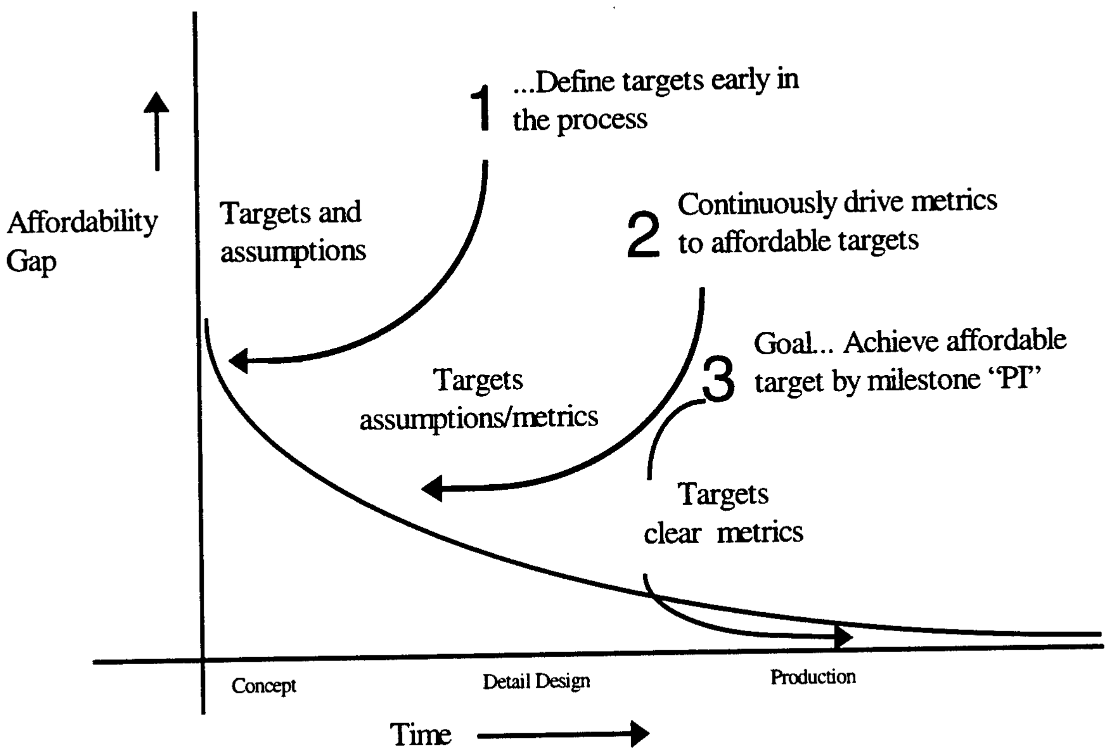

Figure 3-2. Achieving Cost Targets

Ford's experience is that designers seem to have limited knowledge of the physical effects to the manufacturing sites that result from their designs. Thus at the product concept level, the problem currently is *direction*, not complete cost accuracy. Ford is trying to avoid designs that are totally incompatible with their manufacturing facilities. The focus of the Investment Efficiency process is to avoid changing parts that the customer does not see and that do not have quality deficiencies. When Ford does change a part, an objective is to reuse the manufacturing equipment and use that part across several vehicle models (for example, Taurus, Explorer, Continental). Money and resources freed up by this approach can then be focused on growing Ford's business in new markets and paying attractive dividends to shareholders.

The design process enabled by Investment Efficiency has an overriding approach to metrics with a goal of producing the best-in-class products at an affordable cost. Ingredients in this approach include the following:

- Defining targets and metrics up front, based on the Affordable Business Structure (discussed further in Chapter 4) and engineering metrics (for example, carryover parts and processes).
- Tracking metrics and targets versus assumptions through the process.
- Understanding the manufacturing drivers for investment.

After more than a decade of shrinking to hike productivity and efficiency, U.S. companies in general are now eager to wring more profits out of these streamlined operations. Ford personnel indicated that they have achieved a level playing field. But the competition goes on.

Note: Achieving a "level playing field" may be exactly the thing that would be the best result for the Department of Defense and its contractors. That is, achieving efficiency for routine capabilities—thus saving money and resources for distinctive performance gains—is a reasonable objective.

The most recent Ford initiatives reported here could be viewed as a broad implementation of what the Department of Defense has termed CAIV (Cost As an Independent Variable) but focused on more than just unit costs. These new initiatives do not replace other initiatives (like concurrent engineering and Total Quality Management) but become elements of Ford's larger strategy built on integrated product/process development (IPPD).

Ford's more recent experience is that the product realization process, for typical evolutionary product cycles, has been speeded up by nearly 50% (about thirty to forty months). The pilot for a future small car program has resulted in savings of up to 50% of the product/process development cost for a new small car program—on the order of $600 million. At the same time, it provided maximum value to the customer and minimum investment cost to Ford. (Details of this pilot program are contained in Chapter 7.)

It should also be noted that Investment Efficiency is not the only FPDS improvement underway. The entire effort has resulted in reducing the product design cycle and cutting in half the size of a typical vehicle program team.

4. Basic Targets of Investment Efficiency at Ford

In this chapter we discuss how Ford relates price, cost, investment, and profit. We introduce Ford's categories of investment costs and the resulting investment efficiency targets.

4.1 Derivation of Cost Targets

In the past, Ford's Product Development process for a new vehicle program consisted of developing product designs; estimating the tooling, facilities, launch, and engineering costs for those designs; adding a profit margin; and thereby determining the revenue target for the product. This relationship is shown in the following "classic" product development equation:

Product Cost + Profit Target = Revenue Target (Price to Customer)

This process was not substantially different from how other automakers developed their products. The focus was on the company and not the customer. Automakers, in general, believed that the customer would accept a higher price on the basis that the product had more features and functional improvements as compared to the previous model it replaced. This practice sent vehicle prices on a steady climb year over year. Whereas most technically advanced products (e.g., calculators, computers) have fallen in price over the years, the costs of automobiles have steadily increased. The average price for an automobile has risen over the past fifteen years from $10,000 to $20,000. Some of this increase has been attributable to the costs of adding regulatory-based equipment to the products (e.g., emissions related, air bags, strong bumpers, door panel stiffners) and economic increases.

As prices continued to increase through the 1980s and early 1990s, customers began to find that they could not afford the payments associated with the purchase of a new automobile. Increasingly, the customers turned to the used car market, and automakers were forced to offer costly rebates and lease incentives to attract consumers to their products.

The automakers, including Ford, came to the realization early in this decade that they could no longer pass their costs on to the consumer. The concept of *value* permeated the industry, and the automakers needed to address this message from their consumers.

Ford's response was the *Affordable Business Structure*. The Affordable Business Structure is a planning framework for costs that guides development of vehicles that are both affordable to Ford and its customers. The focus of Ford's cost structure has been fundamentally changed from an internal focus to one where all costs revolve around the price the consumer is willing to pay for a product. The Affordable Business Structure serves to align and link all functional objectives around this concept: the consumer is king and Ford must direct all its effort to producing products that provide the most customer-perceived value for the dollar.

The Affordable Business Structure allows Ford to have funds available to invest in new product programs, weather economic downturns, grow business profitability in new markets, and pay shareholder dividends. It has specific metrics for financial measurables (return on sales, assets), while maintaining a focus on producing world-class products with world-class quality.

The Affordable Business Structure equation differs from the "classic" approach to product development by shifting the basis of the product development equation from the company to the consumer. As shown below, the basis for product development is the amount the consumer is willing to pay (market price). From the market price, Ford deducts its profit target for the product. The fallout of this equation is the affordable cost. Simply stated, the consumer dictates the product cost for Ford.

Market Price - Profit Target = Affordable Cost

The Affordable Business Structure equation therefore drives each cost element on the vehicle program's income statement. Both variable and fixed costs are outputs of this equation.[1]

4.2 Investment Elements

Ford delineates investment costs for a product program into four categories: Tooling, Facilities, Launch, and Engineering costs.

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1 Ford uses the term "affordable" as a function of product development and manufacturing processes as well as a function of market demand. The student should compare this with the notion of affordability in the defense world as expressed, for example, in the book *Affording Defense* by Jacques Gansler.

- The Tooling category covers costs for equipment in Ford or vendor plants that generally is permanently modified to cater to a particular Ford product, is specifically designed and life limited to the part it produces, touches the part being produced, or is readily relocated. Ford pays lump sum funds to its internal divisions and outside vendors for such equipment. Examples of tooling include stamping dies, welding fixtures, and molds.
- The Facilities category covers costs for equipment at Ford or vendor plants that generally either is not permanently modified to a particular Ford product, not specifically designed for the existing Ford product, does not necessarily touch the part being produced, and often cannot be readily relocated. Ford pays lump sum funds to its internal divisions for facilities costs. Outside vendors amortize the cost of their facilities into the price per part because these facilities can also be utilized for manufacture of other automakers' parts. Examples of facilities include presses, conveyers, ovens, and floor space.
- The Launch category covers costs for all related expenses incurred during the launch of a new vehicle program. Examples would include such things as off-standard labor hours, training costs, and build-ahead-of-prior-model costs.
- The Engineering category covers costs for vehicle development related to design development, product-related testing, and prototypes for engineering testing.

4.3 Key Areas of Investment

Based on historical figures for a new product program, Ford determined that the highest percentage of investment costs were related to Facilities and Tooling (F&T), then Engineering, and finally Launch. Based on this analysis, it was apparent that Ford needed to attack its Tooling and Facilities costs.

Historical figures also indicated that within the Tooling and Facilities costs for a new product program, two-thirds of the costs were related to the Body Structure/Stampings area and the Powertrain Systems (Engine and Transmission related). These were determined to be the high leverage targets for Investment Efficiency.

5. Strategies of Investment Efficiency

This chapter describes how Ford arrived at its Investment Efficiency Initiative based on results of past efforts. The implementation approach—Product and Process Compatibility—is described along with its four main drivers and their targets.

Ford's previous initiatives lacked the following:

- They did not include the creation of an upper management strategy, the incorporation of Investment Efficiency Metrics, nor the discipline to enforce the use of the new metrics at the "gateways" (i.e., milestone reviews).
- They were not based on special Design Rules and Investment Efficiency Metrics in a form easily understood by the product design personnel who are not familiar with the details.
- They lacked special groups, familiar with the richness of the details, to help the product designers apply these required new metrics.[2]

Investment Efficiency is based on three main strategies, listed in the order in which they were implemented at Ford:

- Micro-engineering: Improving cost characteristics of completed component designs (early to mid-1980s.)
- Simultaneous engineering: Manufacturing, assembly, and design engineers working together during the design of components (late 1980s.)
- Product and Process Compatibility: Making sure product designs are compatible with existing manufacturing processes, tooling, designs, and facilities early in the design process (as of this writing.)

As is common in U.S. industry, the earliest implemented strategy is applied the latest in the development process. Product and Process Compatibility is applied very

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2 Ford's Director of Advanced Manufacturing Pre-Program Engineering hopes that sometime in the future product designers may not need this assistance because they will be more broadly based and thus sensitive to costs and manufacturing issues. Today the system would fail without the help of special groups of experts.

early in the design process but is being implemented last. Each strategy is discussed in further detail in the following subsections.

Investment Efficiency has three implementation features of note:

- The formation of two new groups, Advanced Manufacturing Pre-Program Engineering (AMPPE) and Investment Efficiency and Competitive Analysis (IE&CA). AMPPE is composed of senior manufacturing engineers and is the voice of manufacturing very early in the design process. IE&CA is composed of engineers and finance people and is responsible for the design of the Investment Efficiency process. It also aids AMPPE in the development and implementation of metrics.
- Design rules and metrics for achieving Investment Efficiency for the major auto systems. These rules and metrics provide the detail criteria for guiding the product design process.
- Management requirements that these Investment Efficiency metrics be used at the major Product Design Review "gateways" (milestones).

Ford has been using both Micro-engineering and Simultaneous Engineering since the late 1980s. It found that these processes could yield about 10 to 20% savings in product development costs. However, these savings were not enough for Ford to meet its investment targets and provide optimal value to its customer. These processes occurred too late in the development process to drive major reductions in the development costs for the product.

Ford needed a strategy that would bring together product and manufacturing engineers earlier in the product development process in order to understand and control the drivers of investment for the product. Product and Process Compatibility is the strategy that Ford has developed to make this happen. Figure 5-3 is Ford's depiction of the relative leverage that the three strategies have on costs.

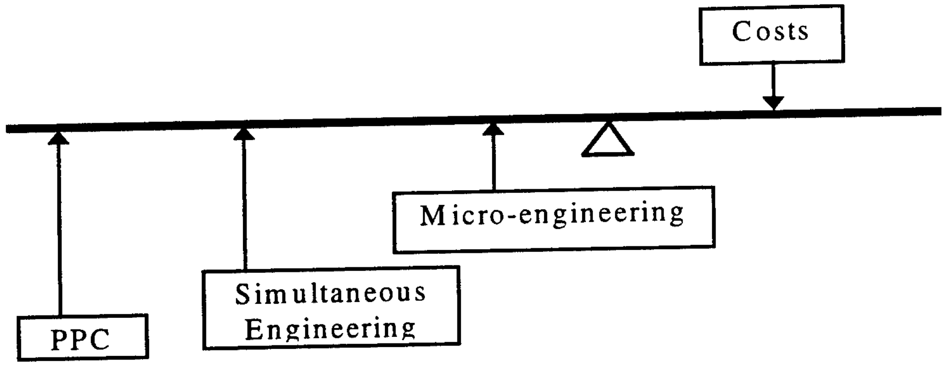

Figure 5-3. Strategic Leverage

5.1 Micro-Engineering

Micro-engineering is a design-process strategy within Ford whereby product teams look at a completed part design to identify tooling opportunities either at the Ford assembly plant or the vendor manufacturing site. The process focuses on optimizing a completed component design to identify tooling opportunities either at the component or assembly process. Micro-engineering occurs latest in the development process. It initially involved the elimination of all Ford-unique requirements on purchased facilities and tooling. Instead, the Investment Efficiency initiative substituted American Society for Testing and Materials standards for Ford-specific requirements where possible.

An example of Micro-engineering would be a detailed review of standards and specifications for a component to eliminate unnecessary costs to the customer.

5.2 Simultaneous Engineering

Simultaneous Engineering[3] is a design-process strategy within Ford whereby both Manufacturing and Product Design engineers work together during the design of a component. The role of the Manufacturing engineer is to provide ideas on making designs "friendly" to manufacture to the Product Design engineer. The role of the Product Design engineer is to take into account system effects, product attributes, and warranty/customer input during the design phase.

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3 Ford was an early adopter of simultaneous engineering practice and influenced early DoD studies on concurrent engineering (e.g., Winner et al. 1988). These studies and others resulted in actions which later developed into DoD's IPPD initiative.

An example of Simultaneous Engineering would be modifying the design of a component to enable easier ergonomics for installation.

5.3 Product and Process Compatibility

Micro-engineering and Simultaneous Engineering remain key elements of Ford's overall investment efficiency strategy. Both strategies serve as the foundation for Product and Process Compatibility. Following the two earlier strategies, the next natural step was to bring product design and manufacturing engineering together at the initiation of the product development process.

Product and Process Compatibility is arriving at the best product and process concept by simultaneously optimizing four main drivers of investment: reusability, commonality, carryover product, and complexity reduction. (These drivers are further discussed in the next section.) Product and Process Compatibility is based on both planning and designing products in a manner to control these drivers of investment. The key to investment efficiency is to employ product and process compatibility efforts early in a product development phase before parts are designed and before assumptions are made. The focus of the process is bringing together product and manufacturing engineering early in the development phase to understand the implications of design alternatives on the manufacturing process.

It is easy for a product development process to become focused on customer needs and lose sight of internal manufacturing issues. When designers are required to consider these factors, it will often require more initial engineering skill to find the right balance to achieve the overall goal. Prior to this initiative, and without sustained input on manufacturing issues, it was not unusual to find that manufacturing issues were overlooked.

To meet customer requirements today, the product must provide the right combination of *features* and *value for the money*. When the balance of features and manufacturing considerations are overlooked in this initial process, it becomes very difficult to correct the problem downstream. Changes after concept design work often compromise either or both areas. Ford's improved Product and Process Compatibility strategy focuses on providing this balance at the initiation of new program work. While providing a more challenging task to the new program team, this strategy will result in the best product at the lowest cost. This combination assures fewer changes, better timing, and good product quality for the customer.

When applied early in the Product Design process, Product and Process Compatibility has demonstrated a potential to reduce design time by up to 33%, reduce engineering workload, and lower total cost.

5.4 Drivers of Investment

This section describes the four main drivers of investment addressed by Product and Process Compatibility: reusability, commonality, carryover product, and complexity reduction. These four drivers interact with each other.

5.4.1 Reusability

Reusability focuses on use of existing prior-model tools, facilities, and processes. Reusability minimizes investment by making use of tools and facilities that are already available and that have already been funded by the company.

5.4.2 Commonality

Commonality focuses on product assemblies, features, product attributes, and facilities and tools shared with other products. The ability to use a common part across several vehicle lines enables Ford to avoid spending capital to design unique tooling (thereby reusing the existing tooling), engineer the unique part, and build prototypes of that unique part. Commonality also allows Ford to amortize its tooling cost over a larger number of parts, and it simplifies inventory for the downstream parts and service activities.

Toyota set the benchmark for commonality within the automotive industry. When Toyota decides to change a part, it implements a process to incorporate that design across its model lineup. For example, a recent trip to a Toyota/Ford dealership revealed that Ford had fifteen different unique designs for a certain underbody component across its models while Toyota had one.

Chrysler has also been successful in driving common parts across its product programs. Commonality is one of the keys to Chrysler's drive to become the low cost producer in the automotive industry. Chrysler follows a "parts bin" approach to developing new model vehicles. For example, the recently introduced Plymouth Prowler roadster was produced for a reported $75 million. This was accomplished by using existing tooled parts from its production vehicles:

- The side view mirror controls, engine, and transmission are from its LH sedan.
- The interior door handles and the gauge faces are out of its Viper sports car.

- The climate controls and rear brakes are from the Neon.
- The plastic vent grilles and front brakes are from its minivans.
- The steering column and turn-signal stalk are from its Jeep Grand Cherokee sports utility vehicle.
- The gear shift lever is from its Eagle Vision sedan.

Ford is aggressively pursuing parts commonality across its vehicle lineup. For example, the recently introduced Ford Expedition shares 50% of its parts with the F-Series truck. Ford's future product plans call for new products to have at least 25% of their parts come "off the shelf" from existing production vehicles. Ford and most automakers have realized that customers are not willing to pay for change just for the sake of change. Therefore, when a high quality component design is established, it is important to drive that design throughout the product lineup.

5.4.3 Carryover Product

Carryover product focuses on carrying over product components, assemblies, or features from the prior generation model of a product, particularly those parts that the customer perceives to have little or no differentiating effect on value. This enables reusability of the existing manufacturing equipment.

In the past, it was fashionable within Ford always to design new parts. "New was better" was the slogan by which engineers consistently churned out new product component designs. "Building the better mousetrap" was the goal of Ford's engineering departments. If an existing part were not performing well in the production vehicle, the first instinct was to redesign the part for the new model, rather than fixing the problem.

The culture within Ford's engineering ranks was one of the main drivers of this philosophy. Young engineers would hear glorious tales of how senior Ford engineering managers had risen through the ranks by developing new, higher functioning designs for product components. Over the years, this bred the "clean sheet" approach to component design that burdened the company with parts proliferation and ultimately led to quality risks as each new product program was launched with a myriad of new component designs.

Ford has drastically changed its view over the last several years. The company has come to realize that customers refuse to pay for change for the sake of change. The focus has to be on only changing parts and vehicle systems from which the customer derives

differentiated value. This could include such things as visible items on the interior or exterior of the vehicle or parts which aid in the ride or handling of the product. That leaves literally hundreds of parts on a product that the customer does not see or care about.

Ford Engineering management has also radically changed its views and reward system for its ranks. Senior Engineering management has challenged its employees to create higher functioning parts by simply modifying existing designs rather than creating all-new parts from a clean sheet. Ford recognized that the most difficult engineering accomplishment was to increase functionality from a carryover part, as opposed to starting from a clean-sheet approach.

Ford now realizes the quality benefits of launching products with a higher degree of carryover parts—those that have already been proven in the field to be reliable and defect free and that are easily assembled. Parts will only change now for new products if demanded by the customer or to fix a quality problem with the existing part.

Ford's future product programs that are based on "freshening" of an existing model (for example, the next generation Taurus) have been given the target to utilize a significant fraction of carryover parts in the design of the new model.

5.4.4 Complexity Reduction

Complexity reduction focuses on reducing the intricacy of a product or manufacturing process. The ability to reduce part complexity will increase commonality of parts across models.

Ford is moving aggressively to reduce its corporate part complexity. In 1994 it established a Complexity Reduction office that is responsible for studying over one hundred major component commodities and for recommending strategies for reducing the number of unique designs in each grouping. For example, Ford is reducing the number of designs for air extractors from 14 to 5, batteries from 36 to 8, power distribution boxes from 12 to 2, and cigarette lighters from 21 to 1.

What this means to Ford's product teams is that if they plan to change any of these commodities on their program, they must select one of the corporate designs in the "parts bin" for that commodity. This will eliminate the tendency for each product team to design its own unique part for that commodity.

Reducing part complexity will enable Ford to save money on designing and building unique tooling, reduce costs for engineering testing and prototypes, and increase

downstream savings by simplifying the inventory for its Parts and Services division as well as its assembly plants. It will also yield quality benefits as proven existing part designs are used on new products.

Ford has also established overall corporate targets for complexity reduction. Ford has targeted to reduce the number of vehicle platforms (components that make up the underbody of a vehicle) by 50%. It also plans to reduce the total parts in its corporate "parts bin" by 30% by eliminating unique designs through the aforementioned commodity reviews. All new products to Ford (i.e., new segment vehicles) will be targeted to use parts from the corporate "parts bin." "Freshening" programs for existing products will be targeted to use a larger percentage of parts from the previous model or the corporate "parts bin."

Ford also has plans to reduce the manufacturing complexity when it does produce a new and unique component. For example, targets have been established to reduce the number of operations per part for stamped parts, and one of the focuses of Product and Process Compatibility workshops is to design new parts that can be processed through fewer workstations than the previous design. This will allow Ford to reduce its expenditures on its manufacturing equipment, further driving investment efficiency.

6. Product and Process Compatibility Tools

Ford's organizational and process restructuring had to address the following issues:

- Understanding that designers of large complex systems do not necessarily understand the cost and investment impact issues involved with detail design. Similarly, their understanding of the constraints and capabilities of manufacturing systems is weak.
- The need for a strategy to control proliferation of product and component variations and to address investment efficiency, market drivers, and available technology.
- Management maturity that realized that detailed cost-process knowledge resident in a corporation (or available for purchase) must be re-packaged and brought forward with experts to the initial product design point.
- Management realization that to implement these policies required new Design Rules and Investment Efficiency Metrics to be created to guide all aspects of product design.
- To impose structure on the development process, these new metrics must be used at the major program review points ("gateways").

Ford has developed four main tools to drive Product and Process Compatibility in its platform teams: Investment Efficiency Metrics, Manufacturing Design Rules, Generic Product/Process Concepts, and Life Cycle Cost Analysis. Each is discussed in the following subsections.

The new strategies, tools, and methods also required new training programs supported by books of metrics, design rules, a training guide, and two videos.

6.1 Investment Efficiency Metrics

Product and Process Compatibility is based on the concept of controlling the physical drivers of investment (reusability, commonality, complexity reduction, and carryover product) for a product. A car or truck is an extremely complex product with a

myriad of vehicle systems and components. Each vehicle system has its own unique drivers of investment that need to be first identified and then measured through a metric.

Ford began the development of its Investment Efficiency Metrics by identifying twenty-six major systems of a vehicle that had unique drivers of investment. Examples include engines, transmissions, seats, instrument panels, brakes, and suspension components.

Ford then assembled cross-functional teams of subject matter experts for each system. Team members included product engineers, manufacturing engineers, and vendors. The team's assignment was simple: "What physically drives investment dollars for your system, and how would you measure these?" Each team identified its physical drivers of investment and categorized them as a driver of reusability, commonality, carryover product, or complexity reduction. Then the team determined a metric for tracking the driver.

Each team reviewed its findings with an oversight committee, the Investment Efficiency Council, consisting of senior management from Product Development, Manufacturing, and Purchasing. The information was then finalized and made available for product teams.

6.1.1 Ford's Metric Process

Investment Efficiency Metrics are the cornerstone of Product and Process Compatibility efforts at Ford. They are the tool by which product teams control the drivers of investment for their product program. Table 6-1 summarizes the process.

The process begins shortly after team formation during the Pre-Strategic Intent phase. This is the highest leverage point for Investment Efficiency for a product as the assumptions are just being developed. The product team reviews the Manufacturing Knowledge Base, a compilation of information regarding the "hardpoints" of the existing product and the assembly equipment put together by Ford's Advanced Manufacturing Engineering group.[4] This data enables the team to identify the areas of the vehicle that will be expensive to change because of limitations of the existing manufacturing equipment and the product. This upfront knowledge allows the team to tailor its product as-

4 "Hardpoints" are specific locations on the vehicle's body pan to be used as attachment and reference points for all tooling, welding, and assembly for the entire vehicle. The approach being adopted across the vehicle industry is that there should be four hardpoints in common for all products in a company's line.

sumptions to make changes to meet customer needs for the product without major changes to the existing manufacturing process. Under this approach, if a team does decide to make a change that will drive significant costs, it understands the effect of that decision.

Table 6-1. Metrics Process

Step	Action	Objectives
Pre-Strategic Intent: Review Manufacturing Knowledge Base.[5]	Identify limitations of existing manufacturing equipment and product.	1. Identify vehicle areas expensive to change. 2. Avoid manufacturing changes. 3. Make informed decisions that affect manufacturing costs.
Set macro targets.	Set high-level targets for major physical investment drivers.	1. Align early metrics with Affordable Business Structure. 2. Avoid drift to unaffordable assumptions.
Efficiency Council review.	Senior development, manufacturing, and purchasing managers review macro targets.	Review and consensus.
Set system targets (example systems: body, engine/transmission).[6]	Set physical metric targets for each system.	1. Detail physical metrics. 2. Align total system investment targets in proportion to subsystem investment allocations.
Product/Process Compatibility workshops.	Detail relationship of product designs with physical processes.	Align detailed product assumptions with physical targets per system.
Efficiency Council review.	Senior development, manufacturing, and purchasing managers review detailed targets.	Fix the metrics that must be met throughout development.
Using metrics and targets.	Design teams measure emerging designs using metrics and compare with targets.	Meet the targets in the actual design.
Review designs.	Subteams report status versus targets to project manager at regular team reviews.	Keep the team on target.

5 The Manufacturing Knowledge Base was created and is maintained by the Advanced Manufacturing Engineering Group.

6 "Systems" here are equivalent to "subsystems" in DoD parlance.

The team begins the process by setting macro targets for the major physical investment drivers for the product. Examples of metric targets set during this stage include the following:

- Reusability of assembly line equipment
- Floor space utilization in assembly plant
- Reusability of body construction and powertrain tooling and facilities
- Percentage of carryover parts utilized
- Percentage of common parts (from Ford's parts bin) utilized

Targets for these physical drivers of investment are based on the investment dollars allocated to the program from the Affordable Business Structure. For example, a $500 million product program will have a much higher percentage of Assembly Line Equipment Reusability (e.g., 90%) than a $1.5 billion product program (e.g., 60%).

The goal of these early metrics is to get alignment of the macro product assumptions with the Affordable Business Structure dollars early in the development stage. This will ensure the product team does not "drift" into creating product assumptions that are deemed unaffordable later in the development process. *This is the most crucial point in Ford's Investment Efficiency process: It fundamentally sets the product program's macro assumptions in line with what is affordable to the company—and ultimately the customer.*

Note: The auto industry has a long history of striving for standard processes and designs, benchmarking (both internal and external), and formalizing this information into weighty (10-inch-thick) books. For example, there are such books on standard design and processes for designing and manufacturing engines, stampings, transmissions, and gear tooth stresses.

The problem is not a lack of technology but rather not enough process management. That is, methods are required for standardizing processes like common manufacturing locators and weld-lines within and between auto programs. See Table 6-2 for examples of how the metrics develop through the product development phases.

Table 6-2. Investment Efficiency Metrics By Phase

Advanced Development/ Annual Process	Pre-Strategic Intent	Early Design	Development	Build up to Job #1
General Targets	**General Targets**	**Specific Targets**	**Specific Targets**	**Objectives**
% Part Reduction Carryover Parts Common Parts	% Part Reduction Carryover Part Common Parts	% Part Reduction Carryover Parts Common Parts	Count (Absolute) New Parts Carryover Parts Common Parts	Count (Absolute) New Parts Carryover Parts Common Parts
Number of Platforms	Specific Platform & Range Hard-points	Specific Platform & Range Hard-points	Specific Platform & Range Hard-points	Specific Platform & Hardpoints
Powertrain Combinations	Powertrain Combinations	Powertrain Combinations	Powertrain Combinations	Powertrain Combinations
	Labor Hours (% Less Than Car-ryover)	Labor Hours (Absolute)	Labor Hours (Absolute)	Labor Hours (Absolute)
		Initial Variable Cost & Invest-ment	Variable Cost & Investment (Ab-solute Targets by Operation)	Variable Cost & Investment (Ab-solutes by Operation)
	Body-in-White Combinations	Body-in-White Combinations	Body-in-White Combinations	Body-in-White Combinations
			Stamping Operations Per Part	Stamping Opera-tions Per Part
			# of Close-out Welds	# of Close-out Welds
			Reusability of Processes	Reusability of Processes

Note: The phases are not named exactly like this at Ford.

After developing its macro physical targets, the team presents them and the work-plans to the Investment Efficiency Council for review and consensus.

After the Strategic Intent Phase, the product team begins to form subteams, each of which is responsible for a vehicle system on the product (i.e., Engine/Transmission Team, Interior Team, Body Structures Team). These teams go through a metric target setting process for their vehicle systems. For example, the Body Structures team would be responsible for having physical targets established for its vehicle system. The teams set their physical targets at a level that is comparable to the amount of total vehicle investment dollars that has been allocated to them. An example of metrics for the Body Structure team is shown in Table 6-3.

Table 6-3. Body Structures/Stampings Investment Metrics

Driver	Metric
Total # parts/vehicle	# parts
Annual volume	Volume/capacity—A, B, C Dies
Commonality/carryover	% carryover parts % common parts % carryover process
Dies/part	# operations per die set # exceeding four operations # dies/part # double attached % progressive dies
Common architectures	% common joints % carryover locators % re-use of tooling
Common assembly	# load-weld-load % common assembly sequence % common tools for derivatives
Reusable tooling	# carryover stations # carryover respot # carryover inspection stations
Integrated build	Additional floor space list units
Labor/unit	Hours/vehicle

Note: These metrics are at a detail level with respect to the manufacturing process. This example illustrates the flow-down from the high-level investment efficiency strategy to the detailed metrics applied to product/process designs.

It is important to understand that early cost estimates are necessarily imprecise. Ford's management appreciates that product concept targets and assumptions may not be rigorous, but as the program matures, metrics should continuously drive towards affordable targets so that by program approval clear verifiable metrics exist, as Figure 3-2 illustrated previously.

The product teams begin a series of Product and Process Compatibility workshops to drive the designs of vehicle subsystems to the physical targets established. The objective of these sessions is to align the detailed product assumptions with the physical targets established for each system.

The team then returns to the Investment Efficiency Council to review these more detailed targets and the results of their Product and Process Compatibility workshops.

The metrics are used throughout the product development process. As designs are established for vehicle systems, the effects to the physicals are measured against the targets for each system. Each subteam reports its status as compared with targets on the physicals to the project manager during regular team reviews.

6.1.2 Milestone Review Process

The milestone schedule has been compressed but exit criteria remain essentially the same. What has fundamentally changed is the management of the review activities. Major milestone reviews are now carried out by a new Oversight Committee composed of the Vehicle Center's Vice Presidents. Previously, designs were reviewed up to Program Definition by Design Managers not totally familiar with costs or investment issues. Besides changing the management of the review process, management has now dictated that Investment Efficiency Metrics be used at all major program reviews. The new process requires that Investment Efficiency Metrics and product design rules be used at the front end of the product development cycle.

6.2 Manufacturing Design Rules

Ford's Manufacturing Design Rules identify the critical parameters or constraints that make up the manufacturing processes and that are the drivers of Facilities and Tooling investment. The rules provide the basic knowledge to assist product designers and engineers to drive towards the Investment Efficiency Metrics targets that have been established. They serve to educate the designer and product engineer on the manufacturing implications of their decisions.

Ford's Manufacturing Design Rules are grouped by major areas such as Stamping, Body Structures, Powertrain, Electrical, and Interior. The use of the rules will assist Ford in driving towards the following:

- Common assembly architecture
- Common assembly sequence
- Common assembly locators
- Reduction in the number of die operations per part
- Plans for accommodating future models and powertrains

For example, a Stamping Design Rule would indicate to an engineer that it is preferred that holes should be placed on a stamped part on flat surface of the part. It is acceptable to have holes placed on a stamped part surface with less than a 15-degree plane. This will allow a press to come straight down and punch the hole. If the hole is on a surface greater than 15 degrees, a secondary CAM operation will be required to punch and trim the hole. This will incur added manufacturing cost to the product. If a hole has to be on a stamped surface greater than 15 degrees, the rule indicates that the engineer should design an embossment into the sheetmetal to allow the press to punch the hole on a flat surface.

As shown in this example, each of Ford's Manufacturing Design Rules indicates to the engineer what is preferred, acceptable, or not preferred. The engineer also is provided with an explanation as to why the costs would increase (e.g., secondary CAM operation required) if the rule is violated.

Examples of Detailed Design Rule Types

The following examples provide a brief glimpse of other types of design rules used within Ford's component areas. They are provided merely to indicate the breadth and depth of the initiative.

Design Rules for Body Construction

- Same number of panels and joint/sealer designs permitting common bodyshop process
- Underbody and structure: best opportunity
- Skin panels: styling flexibility with common joint/sealer designs

Note that "styling flexibility" is being constrained by an opportunity for cost savings by making joint designs common.

Common Assembly Sequence Design Rules

- Make common across vehicle lines.
- Load small parts in subassembly tools.
- Load large parts in large tools in the initial station.
- Avoid designs requiring sequential assembly, i.e., avoid load-weld-load conditions.

The last bullet means that a sequence in which a number of part loads are followed by a single welding step is preferred to one in which loads are interspersed with welds.

Design Rules for Common Locator Holes and Surfaces

- Common for body construction and component assembly
- Common locators:
  - From stamping through assembly
  - Between vehicles on the same platform
  - From present generation to next generation vehicles
- Changes limited to one plane
- Underbody and structures most important

Sample Design Rule worksheets for two of the twenty-six component areas were shown to the study team but not released. They were organized by general Design Rule category (e.g., reusability, commonality).

6.3 Generic Product/Process Concepts

Generic Product/Process Concepts provide designs and processes that are "off the shelf" and that have been optimized for both Product and Manufacturing requirements. These concepts enable Ford to achieve greater commonality across its product lineup and to achieve greater reuse of its manufacturing equipment.

Ford has been working in several areas to arrive at common part designs and manufacturing processes in an effort to reduce costs. Examples include the following.

- Generic body architecture

- Generic body shop
- Instrument panel structures
- Powertrain components (e.g., engine blocks)
- Climate control components

These tie in with Ford's work on creating common vehicle platforms for its product lineup. The concept of common vehicle platforms is the key enabler to achieve Flexible Manufacturing.

Flexible Manufacturing is the ability of manufacturing and product design to respond in the shortest amount of time-to-market changes with products that profitably meet customer needs. The advent of common platforms within Ford will enable the development of distinctly different products derived from a common set of assembly tooling. For example, a Ford plant could produce Common Platform "A" that includes a sedan, coupe, and mini-sports utility vehicle, all in one plant traveling down a common assembly line. As customer demand shifts from one model to another (say, the sedan to a mini-sports utility vehicle), the mix of product could change quickly to meet market needs.

Ford's vision is to use a limited number of core platforms from which multiple derivatives could be launched. This will enable Ford to produce more distinctly styled cars and trucks, for relatively low investment costs, thereby achieving its goal of investment efficiency—the greatest value for the investment dollar. To the customer, the vehicle will appear unique, but the platform components the customer does not see will be common across multiple derivatives. The challenge facing Ford and other major automakers is how to implement such a strategy.

Ford defines a platform for a vehicle as three main structural assemblies that make up the underbody of the vehicle: Front End Structure, Front Floorpan, Rear Floorpan. The costs to tool and assemble these complex systems are the most expensive portion of investment for a Ford vehicle program. An internal Ford study in 1995 indicated that it had thirty-two unique platforms within the company. Some of these platforms' dimensions were within millimeters of others. In essence, Ford spent millions of dollars in the past to design unique platforms that were essentially similar in dimension. Beyond the cost for tooling each platform, Ford also expends engineering resources for development and testing.

A 1992–93 Ford analysis showed gains that could be accomplished by a "Factory of the Future" that incorporated Flexible Manufacturing in a sensible way. Example gains of a possible Factory of the Future were shown for powertrains with manufacturing based on advanced flexible manufacturing cells. An estimate was made that a Factory of the Future would be able to reduce downstream costs 70 to 80% at each subsequent product changeover for an initial 25 to 35% increase in facilities and tooling over then-current practice. ("Downstream" here refers to changeover points to later products and not to the downstream costs—logistics, ownership, and maintenance—of the current product.) This leads to the issue of bringing downstream cost analysis to bear in the upstream design process, as discussed in the next section.

Ford's drive towards common platform is in the process of being implemented as part of the Ford 2000 reorganization. Ford has successfully aligned its global product cycle plan around the aforementioned platforms. This approach is projected to save billions of dollars for the company over the next several years.

6.4 Life Cycle Cost Analysis

Vehicles are cyclical products that must be updated regularly to meet government or corporate regulation and to provide new exciting features and modern styling. Ford generally categorizes product changes within a cycle as all-new product, major freshening, and minor freshening, based on the degree of change.[7]

For example, Ford might introduce an all-new product offering in the 1997 model year with a twelve-year cycle. It will then plan to conduct a minor freshening on that product after four years, a major freshening after eight years, and will replace the product altogether at the end of the twelve-year cycle.

Because of the cyclical nature of the product, extensive planning is required in the initial product design to allow manufacturing flexibility for mid-cycle changes at an affordable level. Often this manufacturing flexibility requires additional amounts of capital expenditures at the start of the cycle to realize downstream benefits at the mid-cycle freshenings.

In the past, Ford's Product Development System was heavily focused on optimizing costs for the initial product. As costs were pared down, incremental capital re-

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[7] Note that "life cycle costs" at Ford refer to the life cycle of a product line such as the Ford Taurus. In DoD, life cycle costs generally refer to the costs of owning, operating, and maintaining systems.

quirements for manufacturing flexibility were often the first to be eliminated. Ultimately, this led to struggles at the mid-cycle freshenings: The product teams could not afford to make substantial product changes because of the inflexibility of the manufacturing equipment. The debate was whether to optimize profitability over the near term versus the entire product life cycle. In addition, Ford's performance system was not set up to reward decisions that optimized long-term profitability. The focus for a platform team manager was to optimize profits for the upcoming product change in the cycle.

With Ford 2000 and the development of Affordable Business Structure, Ford has shifted its emphasis to product cycle profitability. Ford realizes that flexibility needs to be planned into new product offerings to ensure lower mid-cycle freshening program costs. Platform team managers now are responsible for total product cycle profitability; therefore, their focus has shifted to optimizing total product cycle profitability. Senior management has also realized that incremental capital expenditures may be required during the initial program if they can be proven to lower mid-cycle freshening costs (see Figure 6-4).

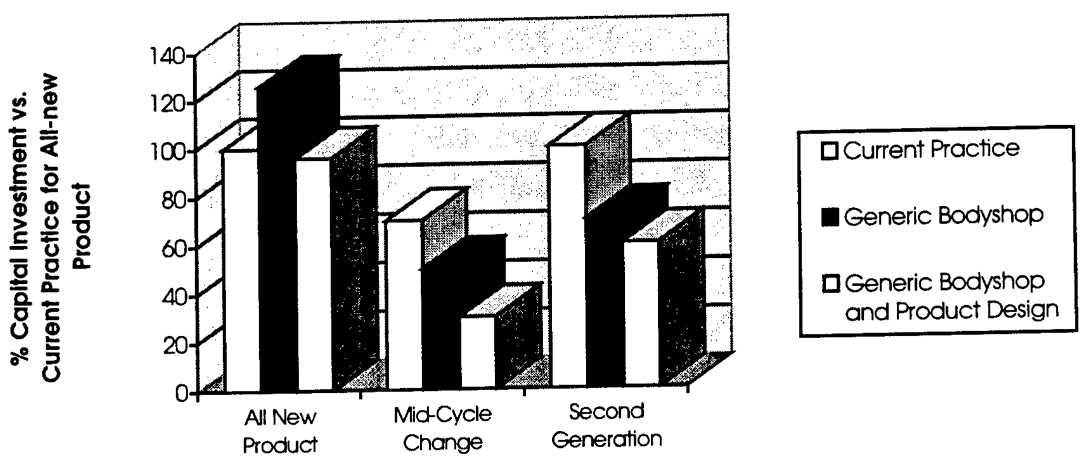

Figure 6-4. Planned Flexibility Yields Cost Savings During the Life Cycle

As part of Ford 2000, the company has also changed its financial system to place more emphasis on total cost rather than optimization of any individual cost element (i.e., Investment, Material, Freight, Labor, etc.). Investment in one element cannot be viewed in isolation with efforts focused only on reducing that cost element. Product decisions will be made that will be in the best interest in maximizing profitability for Ford as a whole.

7. Future Small Car Program Pilot

Ford has already piloted its Investment Efficiency process on several future model programs. Pilot results have been positive and the company is now in the process of implementation on all future model program teams. The following is a brief summary of one of Ford's pilot studies, the future small car program.

The future small car program was the initial pilot of Ford's Investment Efficiency initiative. This product will be global in line with the Ford 2000 vision. It will be sold in markets around the world and produced in Ford plants in Europe and North America. The product lineup will include a three-door, four-door, and station wagon.

Before Ford 2000 was implemented in January 1995, work had already begun on this pilot program. Initial product assumptions called for unique versions of the vehicle to be produced in Europe and North America. Ford 2000 and its global platform vision challenged the team to create one platform to serve all worldwide markets.

The North American plant's present assembly process was distinctly different from that of the European plants that would be assembling the product. The first approach was to change over the North American plant to the European process to achieve consistency and uniformity in assembling the product. This would result in a new body shop being built at the North American site, alongside the present building, and all new processing equipment to be installed. The present bodyshop at the North American facility had received a major refurbishment in 1989 with new equipment.

This approach was extremely expensive as an entirely new building would have to be added to the North American site. In addition, the design of the vehicle had not been optimized for compatibility with the existing manufacturing equipment in the European plants. This resulted in low levels of reusability for the European locations. The product team soon found itself two to three times over its Affordable Business Structure investment target.

The product team dedicated one month to employ a Product/Process Compatibility "blitz" to lower its investment levels while still providing the customer with the product requirements being demanded.

The initial phase of the blitz involved identifying the physical drivers of investment for the product. The largest driver of investment was the fundamental difference in the manufacturing process between the North American and European assembly locations. Another large driver of investment was the product complexity among the models, that is, the number of unique parts assumed for each model. The focus of the Product Process Compatibility blitz was to address these two issues.

To address the manufacturing process differences, the engineers focused on a new design approach that would enable the product components to be assembled through either manufacturing process. This eliminated the need for the new addition at the North American plant—thereby reducing floor space as well as allowing the product to be processed through much of the existing equipment. Figure 7-5 illustrates the before-and-after Product/Process Compatibility space requirements. The team also spent time going through each component to understand how design modifications would allow increased reuse of equipment at all plants. One result of this process was a significant increase of plant processing equipment reusability in Europe and North America. Figure 7-6 depicts the amount of reuse in construction tooling and facilities.

To address the complexity issue among the model lineup, the team constructed a complexity matrix. This matrix listed each component of each model. The team then began a process of examining each component on the model lists to understand why it could not be made common among the model lineup. They found that many of the parts could be made common with minor revisions to the proposed designs. This process drastically reduced the number of unique parts that would have to be engineered and tooled for the product.

Figure 7-7 depicts the results from a similar project to develop a new truck. This truck had three versions with various wheelbases and a different roof height for different markets.

By using Product and Process Compatibility to drive the product's assumptions in line with the existing manufacturing equipment and to reduce product complexity, the team was able to save hundreds of millions of dollars and drive down towards its Affordable Business Structure investment target. This was done without sacrificing product content and features that the customer demands from this product. The team was highly successful in its application of Product and Process Compatibility, and their work has served as the basis for the launch of the process across all of Ford's platform teams.

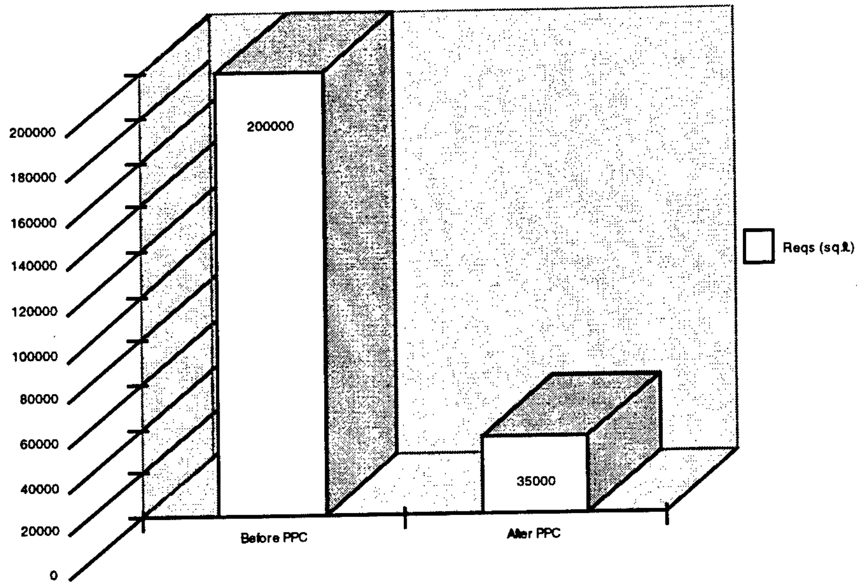

Figure 7-5. New Building Requirements Reduced 83% (Car Project)

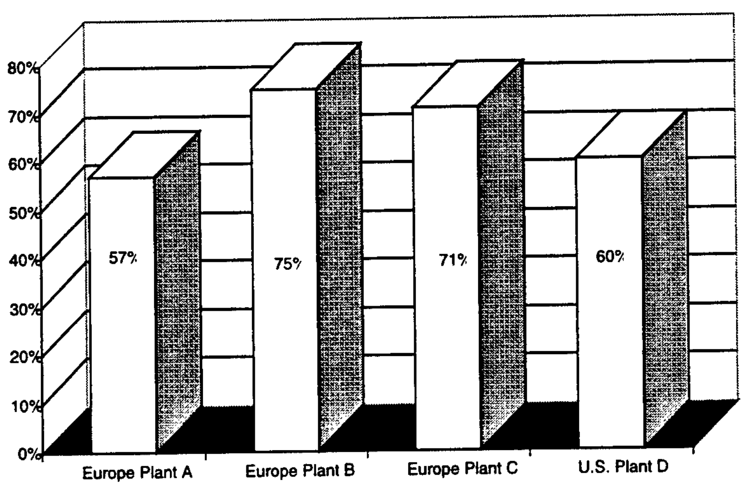

Figure 7-6. Reuse of Construction Tooling and Facilities (Car Project)

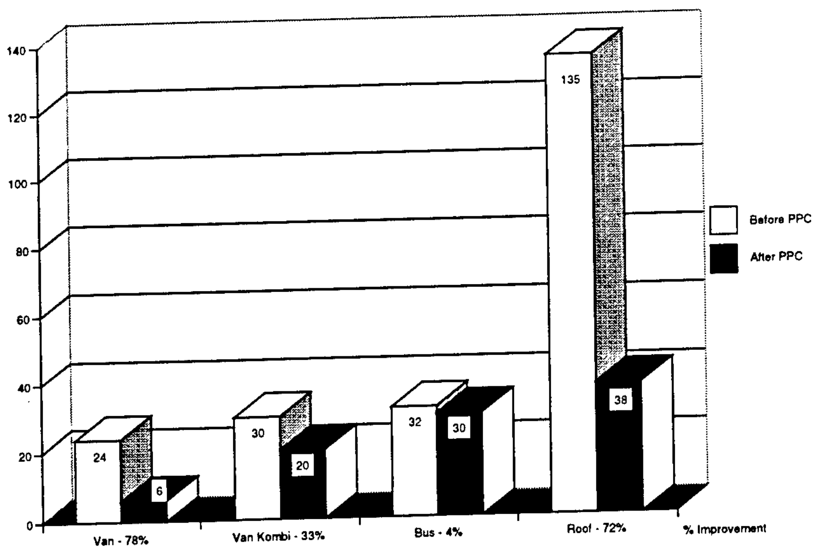

Figure 7-7. Number-Unique Sheetmetal Parts (Truck Project)

One new and different aspect for Ford in this initiative is the maturing view of management to the larger problems of the Product Development Process and the necessity for management to take an aggressive role in defining clear goals and the methods for achieving them as well as the organizational structure to implement them effectively.

Note: The "blitz" described in this anecdote is not a "Tiger Team." The Tiger Team approach is so situation dependent that very little systematic improvement is gained. Tiger Team results are not transferable to other products because they are too product specific and the processes are too unique.[8] Here, Ford management used the small car project as a pilot of a permanent, systemic process change.

[8] See H. K. Bowen et al., *The Perpetual Enterprise Machine*, Oxford University Press, 1994.

8. Organizational Changes at Ford

Ford has learned many lessons during the development and implementation of its Investment Efficiency process. Chief among those is that the process will only work with true cross-functional participation. In the case of Ford, this means having representation from such activities as Manufacturing, Product Engineering, outside vendors, Sales and Marketing, and Purchasing.

At the heart of this cross-functional team effort is the relationship between the Manufacturing and Product Development groups. The biggest challenge for Ford was getting these two activities together earlier than ever before in the Product Development phase. In the past, the relationship between these activities was sequential in nature: Product Development developed assumptions and engineered the product and then handed those plans over to Manufacturing for implementation. This relationship precluded effective dialogue between these organizations during the development process, with the result being products that were fundamentally incompatible with the existing manufacturing equipment/processes.

8.1 Implementing the Investment Efficiency Process

As part of Ford 2000, two organizations were created to create and implement the Investment Efficiency process: Advanced Manufacturing Pre-Program Engineering (AMPPE) and Investment Efficiency and Competitive Analysis (IE&CA). These groups have representatives on each of the platform teams during the product development process. Their role is to facilitate Product and Process Compatibility efforts on the platform teams.

The AMPPE group is composed of Manufacturing Engineers, all with extensive experience (at least fifteen years). The group is divided into departments based on Ford's assembly process. There are departments associated with Stamping/Auto Assembly, Powertrain (Engine/Transmission) Assembly, and Automotive Components (e.g., Instrument Panel) Assembly. There is also a small department within the group that is involved in Ford's Product Cycle Planning process. The role of AMPPE is to be the voice of Manufacturing on the platform team during the early product development phase (before formal program approval). This includes sharing with the platform engineering team the

information regarding existing manufacturing equipment at the assembly site, maximizing reuse of the equipment, and taking advantage of opportunities to reduce manufacturing complexity (i.e., number of workstations required, number of direct labor hours required to assemble product). The AMPPE representative also works with the platform team to set metric targets to control the physical drivers of investment and facilitates Product and Process Compatibility workshops to drive product design alternatives to the metric targets established.

The Investment Efficiency and Competitive Analysis (IE&CA) group is composed of both Product Engineers and Finance personnel who have previously served as members of platform teams. Their role is to lead in the creation of Ford's Investment Efficiency process and to aid the AMPPE group in platform implementation (i.e., setting metric targets, facilitating Product and Process Compatibility workshops). Another portion of the group works on tax abatements and incentives with local municipalities where Ford has established manufacturing sites. The group is also responsible for training Ford personnel on the Investment Efficiency process and for participating in benchmarking studies.

Ford also set up an oversight committee of senior management, the Investment Efficiency Council, to oversee development of the process and conduct platform Investment Efficiency reviews to ensure the process is working. The Council is made up of Senior Management (vice presidents) from Product Development, Manufacturing, and Purchasing, and meets regularly.

In summary, the Ford Investment Efficiency process is based on strengthening the relationship between Product Engineering and Manufacturing early in the product development phase. This is facilitated by the AMPPE and Investment Efficiency groups and overseen by the Investment Efficiency Council. Only when this relationship is strengthened and leveraged will true investment efficiency occur in a product development process.

8.2 Involving the Suppliers in Investment Efficiency

As part of a separate activity, over the last several years Ford has completely changed its relationship with Facilities and Tooling suppliers. Instead of fixed-price competitive contracts, Ford has gone to target pricing and negotiated contracts.

Target prices are developed from the following:

- Benchmarking: both internal and external. (However, benchmarking comparisons of investments are not generally accurate.)
- Looking at similar products (last purchases)
- Historical data
- "Business judgment" (For example, are supplier order books filled or empty?)

Suppliers are reviewed, selected (usually one), and invited to join in the design discussions a year earlier then they were in the past—T-36 instead of T-24 months. They are not paid for this early involvement except under special circumstances.

Since suppliers are involved early, they are also advised of Ford's expectations. And because both parties will be examining the design, Ford expects that the resultant design (at T-24 months) will be the target price minus a "tad," but this is a negotiated stance. For example:

- The target price might have been $30 million.
- Expected reduction might have been 10% ($3 million).
- The final negotiated price might turn out to be $28 million.

In one case, the difference was claimed to be due to extra tooling not included or estimated in the original plan. If there is no agreement, then Ford will rebid the job at the T-24 month point. Apparently, there is still enough time for nearly everything except for items like an engine-block line which can take six months more.

Ford is pleased by the new arrangement because now the suppliers function as team members instead of adversaries.

9. Lessons Learned

Developing and deploying any new process within a company the size of the Ford Motor Company is a difficult challenge. The following lessons learned reported by Ford managers are based upon the last eighteen months of process development and implementation.

9.1 Changing Mind-Sets

Ford's Investment Efficiency process is based upon a fundamental change in mind-set for its product development organization. This mind-set had developed over years and years of developing vehicle programs. Such changes in corporate culture do not occur overnight. An analogy is that of a large cruise ship—the ship does not make 90-degree turns but rather shifts its direction. The expectation has to be that the change will be gradual rather than immediate.

9.2 Understanding the Need for Change

For changes in mind-set to occur, employees must understand why the change is necessary and feel the need for such a change to occur. In the Ford example, a sense of urgency has pervaded the company for the first time since the early 1980s, driving the company to become investment efficient. The company sees increasing pressures from competitors such as General Motors, Chrysler, and Toyota. Financial results indicate that Ford is lagging behind these competitors when it comes to product development costs. At the same time, the company requires increased capital to enter growth markets overseas while maintaining its market share in mature markets with the introduction of new and innovative products. The overseas growth markets require products that are low cost but still provide outstanding quality and exciting features. For Ford, the need for Investment Efficiency is clear both to its management and employees.

9.3 Strengthening Management Support

For such a culture change in a large organization, there must be strong management support and discipline. Management must demonstrate a commitment to the process. In the case of Ford, the establishment of the Investment Efficiency Council to

oversee the development of the process and review progress with the platform teams ensures that employees see senior management support. Ford Product Development Management has strengthened its product milestone reviews, letting no platform team go through the development gateway with an investment status not at or near its investment target. In the past, platform teams would go through these reviews with an inflated status and a promise to get its cost down. Now, these same teams are being told not to show up for reviews if they are not on target.

9.4 Creating Aligned Objectives

The development of aligned objectives is important to implement a process such as Investment Efficiency. Within Ford, there are several manufacturing divisions and a product development group. If each organization is working to a different set of objectives, then any process will fail.

Ford has begun to break down these organizational "chimneys" through Ford 2000's use of matrix management. In addition, Affordable Business Structure targets are the common element to align the business objectives of each organization. Each organization is charged with getting its cost on target with the Affordable Business Structure.

10. Discussion Items

The following questions are provided as starting points for discussions on how the Department of Defense can better integrate cost tradeoffs and cost targeting into its acquisition processes and integrated process teams.

1. What is the DoD parallel to the shift in Ford's markets?

2. What advantages are to be gained by Product and Process Compatibility? Do these have parallels in the Defense systems acquisition environment?

3. a. The design rules and metrics at Ford start at a high level but become quite detailed. Ford created groups of experts to bring detailed manufacturing knowledge to bear early in the development process. What are the implications of these facts on the following: *What should a government program office expect of its development and production contractors? What should a government program office expect of itself?*
   b. Ford uses Product and Process Compatibility workshops to drive the designs of vehicle subsystems to the physical targets established. The purpose of these sessions is to focus the detailed product assumptions with the physical targets established for each system. How would you arrange for a similar process to occur within the product development processes of contractors designing your systems?

4. It was important for Ford to understand its principle cost drivers down to a very detailed level. How can the Department of Defense gain this understanding, given that it must work through its contractors? What contracting mechanisms are available that would cause the contractors to identify the cost drivers at a sufficient level of detail both for themselves and for the government?

5. What special training is required to understand Investment Efficiency and Product and Process Compatibility in the Defense systems context? What training should be provided to bring government and industry's engineers to a level where special groups of experts on costs and investments are no longer required? Does the Department have a role in the education and training of the engineering work force in industry?

6. Reuse of various categories is a fundamental concept at Ford. What are various types of reuse that would benefit defense system acquisitions in costs, investment, and reli-

ability? How could the Department of Defense arrive at a situation where processes and facilities are routinely re-used for missiles, tanks, aircraft, electronics?

7. There are many kinds of costs to try to minimize in tradeoffs. Among them are marginal unit costs, total development and manufacturing costs assuming a given volume, investments over some range of systems (e.g., all missiles), and others. Which of these measures is important in various defense systems acquisition environments? Are there tradeoffs among these different costs?

8. What is the relevance of Ford's use of metrics at its "gateways" to the Department of Defense's milestone review process? What is the relevance of the composition of Ford's review committee? What is the relevance of the workshop process?

9. How does reuse of physical entities (for example, components) apply in areas with very fast-moving technological progress (for example, electronics)?

10. What management actions, at various levels of management, would be required to implement an investment efficiency strategy such as that described here (a) within your acquisition domain and (b) at a DoD contractor?

11. Ford managers pointedly stated that technology is not the fundamental issue but that "the process" is. What is the distinction they are emphasizing to us? What process are they referring to? How does that relate to the acquisition area you are involved in?

12. Compare the major points of Ford's Product and Process Compatibility and the Department of Defense's IPPD and CAIV initiatives both in theory and current state of practice. In particular:

    - Management commitment
    - Motivation
    - Team structures
    - Relevant costs
    - Timely development and treatment of detailed targets
    - Application across projects
    - Consideration of product life-cycle costs
    - Supplier relationships
    - Ability to capture accurate customer requirements
    - Anything else you think relevant

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GLOSSARY

Affordable. Ford uses the term "affordable" as a function of product development, manufacturing processes, and market demand. See the **Affordable Business Structure equation**.

Affordable Business Structure. Ford's planning framework for costs that guides development of vehicles that are both affordable to Ford and to its customers. All costs revolve around the price the consumer is willing to pay for a product, and Ford must direct all its effort to producing products that provide the most value for the dollar. (Compare with the **"Classic" product development equation**.)

Affordable Business Structure equation. The Affordable Business Structure equation differs from the "classic" approach to product development by shifting the basis of the product development equation from the company to the consumer. The basis for product development is the amount the consumer is willing to pay (market price). From the market price, Ford deducts its profit target for the product. The fallout of this equation is the affordable cost.

Market Price - Profit Target = Affordable Cost

(Compare with **"Classic" product development equation**.)

Carryover product. A driver of investment, a carryover product is a product component, assembly, or feature "carried over" to the new model from the prior generation, particularly a part that the customer does not perceive to differentiate value. This enables reusability of the existing manufacturing equipment.

"Classic" product development equation. In the past, Ford's Product Development process for a new vehicle program consisted of developing product designs; estimating the tooling, facilities, launch, and engineering costs for those designs; adding a profit margin; and thereby determining the revenue target for the product. This relationship is shown in the "classic" product development equation of

Product Cost + Profit Target = Revenue Target (Price to Customer)

(Compare with the **Affordable Business Structure equation**.)

Commonality. A driver of investment, commonality is the ability to use product assemblies, features, product attributes, and facilities and tools shared with other products. An example is using a common part across several vehicle lines, thus allowing Ford to *avoid* spending capital to (1) design unique tooling, (2) engineer the unique part, and (3) build prototypes of that unique part.

Complexity reduction. A driver of investment, complexity reduction reduces the intricacy of a product or manufacturing process. The ability to reduce part complexity will increase commonality of parts across models.

Concurrent engineering. A systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements. (Winner et al. 1988, 2; Nevins et al. 1989)

Cost As an Independent Variable (CAIV). A Department of Defense acquisition reform initiative. It requires that cost be set in advance of development rather than to emerge as an outcome of development.

Flexible Manufacturing. The ability of manufacturing and product design to respond in the shortest amount of time-to-market changes with products that profitably meet customer needs.

Ford 2000. An omnibus reorganization of Ford's processes.

Ford Product Development System. A cross-functional process that involves all Ford development and manufacturing activities and suppliers. Its goal is to improve quality, cost, and time to market. Created as part of the Ford 2000 reorganization.

Freshening. Ford generally categorizes product changes within a cycle as all-new product, major freshening, and minor freshening, based on the degree of change. For example, Ford might introduce an all new product offering in the 1997 model year with a twelve-year cycle. It will then plan to conduct a minor freshening on that product after four years, a major freshening after eight years, and will replace the product altogether at the end of the twelve-year cycle.

Gateway. Ford's milestones where program reviews are held and product/process plans are measured on the basis of product features versus costs to achieve. No platform team is permitted to go through the development gateway with an investment status not at or near its investment target.

Generic Product/Process Concepts. One of the four main tools to drive Product and Process Compatibility in its platform teams, Generic Product/Process Concepts provide designs and processes that are "off the shelf" and that have been optimized for both Product and Manufacturing requirements. These concepts enable Ford to achieve greater commonality across its product lineup and to achieve greater reuse of its manufacturing equipment.

Hardpoints. Specific locations on the vehicle's body pan to be used as attachment and reference points for all tooling, welding, and assembly for the entire vehicle. The approach being adopted across the vehicle industry is that there should be four hardpoints in common for all products in a company's line.

Integrated Product/Process Development (IPPD. A management technique that integrates all acquisition activities starting with requirements definition through production, fielding/deployment, and operational support in order to optimize the design, manufacturing, business, and supportability processes. At the core of IPPD implementation are Integrated Product Teams. Some consider IPPD to be Concurrent Engineering renamed.

Investment Efficiency. The ability to simultaneously minimize investment by Ford and to optimize value for the customer. The goal is to provide the most product for the investment dollar.

Investment Efficiency Metrics. One of the four main tools to drive Product and Process Compatibility in its platform teams, Investment Efficiency Metrics are high-level or detailed measures that indicate whether a product/process design meets project-specific and company-wide cost goals.

Life Cycle Cost Analysis. One of the four main tools to drive Product and Process Compatibility in its platform teams, Life Cycle Cost Analysis at Ford attempts to determine investment and other financial requirements over the lifetime of a product line, including minor and major "freshenings." In the Department of Defense, life cycle cost analysis tries to capture costs of ownership, logistics, operation, and disposal of some type of product.

Manufacturing Design Rules. One of the four main tools to drive Product and Process Compatibility in its platform teams, Manufacturing Design Rules identify critical parameters or constraints that make up the manufacturing professes and are the drivers of facilities and tooling investment.

Micro-engineering. Product teams look at a completed part design to identify tooling opportunities either at the Ford assembly plant or at the vendor manufacturing site. Its goal is to improve cost characteristics of completed component design.

Parts bins. Parts approved for use or re-use in Ford products.

Platform. Three main structural assemblies that make up the underbody of the vehicle: Front End Structure, Front Floorpan, Rear Floorpan.

Product and Process Compatibility. Making sure product designs are compatible with existing manufacturing processes, tooling, designs, and facilities early in the design process.

Reusability. A driver of investment, reusability is using existing prior-model tools, facilities, and processes, thus minimizing investment.

Simultaneous Engineering. Manufacturing and Product Design engineers working together during the design of a component.

Target price. During planning and development, the price at which a product is to be sold to the end consumer.

Thrifting. Removing features and options from a product to achieve an investment target.

Total Quality Management. A management initiative in which the driving objective of a company is to continuously improve the quality of processes, intermediate products, and final products. The intent is to drive costs and schedules down through the elimination of waste and rework.

ACRONYMS

AMPPE	Advanced Manufacturing Pre-Program Engineering
CAD	Computer-Assisted Design
CAE	Computer-Assisted Engineering
CAIV	Cost As an Independent Variable
CAM	Computer-Assisted Manufacturing
DoD	Department of Defense
FPDS	Ford Product Development System
IE&CA	Investment Efficiency and Competitive Analysis
IPPD	Integrated Product/Process Development
PPC	Product and Process Capability
T	Target date for beginning mass production (date of Job #1)

Appendix A. Example Ideas for Discussion Items

Chapter 10 of this paper contains a list of questions and topics designed to stimulate discussion among students of the DoD acquisition process. Responding to a request from the OSD Directorate of Systems Engineering, we are providing additional ideas for the discussion items.[1] These ideas are based exclusively on one author's experience and opinions; and they are only a few of many ideas that might be used to start such discussions.

Many of the discussion items are open ended and could be the subjects of whole books. They are not meant to have pat answers but to promote thought and discussion. The author expects trainers and educators to understand the theory and practice of defense acquisition well enough to go well beyond the ideas expressed below. Students should be able to relate the items to their own situations and organizations.

1. *What is the DoD parallel to the shift in Ford's markets?*

   DoD has faced very real and substantial budget declines since the late 1980s, particularly since the fall of the Soviet Union and the dissolution of the Warsaw Pact. These budget declines have motivated OSD and the Services to augment the DoD approach to IPPD by refocusing attention on the role of cost targeting and control.

2. *What advantages are to be gained by Product and Process Compatibility? Do these have parallels in the defense systems acquisition environment?*

   The idea here is to require that product/process design teams take into account the gross and detailed cost factors entailed by their designs, do this from the earliest conceivable stages of development, and make sure that project and product costs stay within target values.

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[1] This appendix was written by R. Winner & Associates under its subcontract with the Potomac Institute for Policy Studies and is reprinted here by permission of the copyright holder, Robert I. Winner.

Essentially, much of what Ford does is to emphasize *re-use* (see Discussion Item 6). Advantages to be gained include savings derived from various forms of re-use. For example:

- Re-using a part or assembly saves design and testing costs, decreases learning-curve effects, increases economies of scale, and allows resources to be concentrated on truly required new items.
- Designing so as to use an existing manufacturing process saves capital costs in acquiring new equipment, saves downtime due to retooling, saves lead times to acquire and retool, allows amortization of costs over larger numbers of products, and saves manufacturing design, testing, and learning-curve costs.
- Taking advantage of or creating process efficiencies—such as use of certain hardpoints and avoidance of load-weld-load sequences—reduces unit manufacturing costs, reduces re-work, avoids retooling costs, and enables automation efficiencies.
- Because the actual cost factors include capital investments in new plant and manufacturing equipment, there are also potentials for cost savings across projects as well as within them.

Parallels exist within the theories and more complete implementations of IPPD and CAIV—initiatives that are clearly interdependent. However, it might be asserted that the current state of DoD acquisition is better exemplified by only partial implementations. This is the situation Ford found itself in during the early 1990s after it had implemented initiatives on Micro Engineering and Simultaneous Engineering. Nor are there many examples of investment efficiency initiatives across projects in DoD. One is DARPA's Affordable Multi-Missile Manufacturing program which has attempted to promote process re-use within the missile community.

3. *a. The design rules and metrics at Ford start at a high level but become quite detailed. Ford created groups of experts to bring detailed manufacturing knowledge to bear early in the development process. What are the implications of these facts on the following: What should a government program office expect of its development and production contractors? What should a government program office expect of itself?*

Contractors should be required to demonstrate that they have people who understand at a deep and detailed level the connection between designs and costs of current and proposed manufacturing processes. These people should be able to translate detailed knowledge into design rules and targets appropriate to the various phases of product/process design. Contractor management should commit to the development, tailoring, and enforcement of metrics, rules, and targets; and to require that the experts be part of and used by the design teams.

Government program offices need people who can interact as peers with those experts as described in the previous paragraph. These government people should review metrics, rules, and targets at a gross and detailed level to ensure that cost targets will be met. Program offices should expect to be able to convince themselves and to demonstrate at reviews that cost projections are reasonable and can be met. Program offices should also expect that they will have to search out such people within their Services and support organizations. But such expertise is not common.

b. Ford uses Product and Process Compatibility workshops to drive the designs of vehicle subsystems to the physical targets established. The purpose of these sessions is to focus the detailed product assumptions with the physical targets established for each system. How would you arrange for a similar process to occur within the product development processes of contractors designing your systems?

This can be tricky. The Department of Defense is correctly moving towards a policy of not telling contractors how to do things. On the other hand, the military customer has the right to see the results of these workshops and, perhaps, to observe the workshops themselves. Rather than requiring that proposals contain a workshop process, an RFP could require:

- a sequence of target definitions and design analyses that demonstrate the convergence of designs to targets;
- that proposals define the process that will produce these definitions and analyses; and/or
- that proposers define the government participation in this process. Then make sure the proposed participation is in the contract.

The government should be willing to commit that only qualified experts (and their trainees) be allowed to review the outputs and processes.

4. *It was important for Ford to understand its principal cost drivers down to a very detailed level. How can the Department of Defense gain this understanding given that it must work through its contractors? What contracting mechanisms are available that would cause the contractors to identify the cost drivers at a sufficient level of detail both for themselves and for the government?*

The issues are training, process, and contracting.

- Training. The government must have people on its teams who can understand at a detailed level why certain design and manufacturing factors are cost drivers. The government can train people to this level, hire them into the government acquisition commands or laboratories, and require that they be hired into Federally Funded Research and Development Centers and other support contractors.
- Process. The Department of Defense and Services need to maintain dialogues with contractors on these issues informally and through studies, workshops, best-practice databases, internal research and development, advanced concept developments, etc. Of course, the government must scrupulously avoid revealing process improvements, considered by the contractors as the "family jewels," to competitors. Ford was very sensitive to this issue in the process of the present study because it realized how important the detailed process factors are.
- Contracting. The users and buyers need to make sure—early and throughout IPPD—that the metrics, targets, and design rules that contractors implement can reasonably be expected to result in the attainment of overall cost targets.

5. *What special training is required to understand Investment Efficiency and Product Process Compatibility in the defense systems context? What training should be provided to bring government's and industry's engineers to a level where special groups of experts on costs and investments are no longer required? Does the Department have a role in the education and training of the engineering work force in industry?*

Defense engineers and acquisition experts need to be trained in manufacturing technology well enough to understand the cost drivers in the kinds of systems they buy. Cost analysis has historically been done at a gross statistical level; for example, the cost of an aircraft might be correlated to its weight. This variety of information is not very useful in the current context. What is required goes far beyond this and in the direction that informs action decisions. We need to understand such issues as the cost of adding a new process to an assembly line and how to analyze the total technical and cost effects of any new proposed process. We need to understand the limitations on processes so as not to commit to a requirement that falls on the wrong side of a cost-performance elbow i.e., a sharp increase in cost as a function of performance. We need to understand when to use commercial components, assemblies, subsystems, and manufacturing processes. Some of these issues are not well understood by our community, and we must seek out the answers. Another sort of issue for training is understanding the interactions of technology risk (including manufacturing technology), schedule, and cost.

Ford found that existing experts—people with many years of experience—were needed to form the groups that work with project teams to formulate targets and metrics early in the process. The Ford managers interviewed hoped that someday such special expert groups would not be required because enough engineers would understand the downstream effects of design decisions. This is an issue that Ford continues to pursue.

The role of the Department of Defense in the education and training of industrial work forces is a matter of enlightened self-interest. In the past, when the Department needed more scientists and engineers, programs were created to fund the education of the required professionals. Funding of education and training programs for existing defense engineers is an option. The extent and approach to these may seem to resemble budgetary and philosophical issues, but in reality they are questions of economic optimization.

6. *Reuse of various categories is a fundamental concept here. What are various types of reuse that would benefit defense system acquisitions in costs, investment, and reliability? How could the Department of Defense arrive at a*

situation where processes and facilities are routinely re-used for missiles, tanks, aircraft, electronics?

This is a very open question. Re-use of parts, assemblies, subsystems, and manufacturing processes would yield savings. Unfortunately, very little work has been done in the DoD world to determine when such re-use is feasible or desirable. Instead, the "design and build from scratch" culture is widespread in defense engineering, perhaps even to a greater degree than it was at Ford. Re-use of production processes in the form of assembly lines for multiple products is not common. Do you know of any? Re-use of assemblies in more than one product (not counting downstream versions) is unusual. Even use of preferred parts databases (which has many advantages) is relatively recent, and the author is not sure how widespread is its use.

7. *There are many kinds of costs to try to minimize in tradeoffs. Among them are marginal unit costs, total development and manufacturing costs assuming a given volume, investments over some range of systems (e.g., all missiles), and others. Which of these measures is important in various defense systems acquisition environments? Are there tradeoffs among these different costs?*

   All of the ones costs mentioned above are important, and it is important to understand their differences. The discussion leader should be prepared to explain the various ways of measuring cost. It might be interesting to get an example system and contrast the numbers. For example, the B-2 cost figures for marginal unit cost vary considerably from the total project cost divided by the units purchased.

   The real issue is, can the Department of Defense afford to buy enough of a given product—and be able to operate and support it—to make the required operational difference from the status quo? And, over some number of years, will the overall DoD or Service budget support the purchase and operation of the variety of systems required? It may no longer be the case that costs can be used to drive budgets; rather, we appear to be entering an age where budgets need to drive costs—and drive them down.

   Thus, you can look at this issue from two angles, bottom-up and top-down. Bottom-up, you want to drive down unit costs, and to do this you focus on things like product-process compatibility—not only designing products and

processes in an integrated fashion but also trying to re-use as much product and as many processes as possible. Top-down, you can go from budgets, plans, and requirements to the required forces and systems. This gets you to overall cost targets for specific systems. Once you determine the affordable costs, you use the bottom-up approach to get to those costs.

8. *What is the relevance of Ford's use of metrics at its "gateways" to the Department of Defense's milestone review process? What is the relevance of the composition of Ford's review committee? What is the relevance of the workshop process?*

   The Department of Defense and the Services could implement cost target reviews at its own gateways. A 1991 Defense Science Board Study on Simultaneous Engineering of Defense Products and Processes noted the importance of these gateways and recommended that exit criteria be beefed up and more strictly enforced in the DoD review process. Ford found that people whose futures were on the line for meeting costs were the appropriate members of the review committees. The workshop process develops the high- and low-level targets and metrics that lead to meeting the overall cost target. These results are used in the gateway reviews throughout the life of the project.

9. *How does re-use of physical entities (for example, components) apply in areas with very fast-moving technological progress (for example, electronics)?*

   This is a difficult technical issue that has policy implications. We need systems with architectures that allow us to track technological progress even in fast-moving fields like signal processing and general-purpose computers. The Department has used the term "open architectures" to describe this, but this is somewhat different from what is meant by the term in the commercial world. An open architecture in the commercial world is one whose interfaces are published. In the defense world, it means, more or less, one in which components and assemblies can be upgraded on a plug-and-play basis. The economics and technology of such modular upgradeability are not well understood. Nevertheless, the Department needs to pursue this issue and system concepts should be explored that can achieve modular upgradeability.

10. *What management actions, at various levels of management, would be required to implement an investment efficiency strategy such as that described here (a) within your acquisition domain and (b) at a DoD contractor?*

This should be discussed in concrete terms based on the student's own organization. It is not meant to be a theoretical question.

11. *Ford managers pointedly stated that technology is not the fundamental issue but that "the process" is. What is the distinction they are emphasizing to us? What process are they referring to? How does that relate to the acquisition area you are involved in?*

Ford managers are differentiating between design and manufacturing technology on the one hand and the management of the design process on the other. For example, they are saying that robots are not the central answer but requiring sound economic decisions in the design process is what they are after. Of course, as the case study points out, downstream economies might be realized based on implementing more flexible and more expensive process technologies now. Once that is realized, a systematic economic decision is possible.

Again, the last question is meant to be answered in concrete terms based on the student's own situation.

12. *Compare the major points of Ford's Product and Process Compatibility and the Department of Defense's IPPD and CAIV initiatives both in theory and current state of practice. In particular:*

- Management commitment
- Motivation
- Team structures
- Relevant costs
- Timely development and treatment of detailed targets
- Application across projects
- Consideration of product life-cycle costs
- Supplier relationships

- Ability to capture accurate customer requirements
- Anything else you think relevant

These points should be based on facts and observations of the students and their teachers. For example, what policies and actions are evidence of management commitment to IPPD and CAIV? Are the required experts available to development teams in your Service or at your contractors? What costs seem to be important? Are detailed cost targets developed early? Metrics? Design rules? Are design rules enforced? Do you know of investment efficiency initiatives that cover more than one weapon system? How are life-cycle costs dealt with during development? (It is important to understand that Ford defines "life-cycle cost" differently from the Department of Defense. Answer this for both definitions.[2])

Supplier relationships in the car industry have at times been difficult. And the supplier relationship in the Department is unusual. Discuss this "love-hate" relationship. The way the Department deals with user requirements differs substantially from a commercial mass producer like Ford. Theoretically, the Department of Defense ought to be able to do substantially better, but it is not clear that this happens in practice. Why do you think that is? (Discuss the relationship of buyers and users.)

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[2] From the glossary: Life cycle cost analysis at Ford attempts to determine investment and other financial requirements over the lifetime of a product line, including minor and major "freshenings." In the Department of Defense, life cycle cost analysis tries to capture costs of ownership, logistics, operation, and disposal of some type of product.

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13. ABSTRACT (Maximum 200 words)

This case study describes how the Ford Motor Company uses Investment Efficiency to minimize investment and, at the same time, optimize value for the customer. Implementation of the Investment Efficiency initiative is through a mechanism called the Product and Process Compatibility (PPC). This mechanism is discussed in detail, along with Ford's strategies for Investment Efficiency, PPC tools and metrics, the pilot program using the initiative, and organizational changes that resulted from implementation of the Investment Efficiency initiative.

This document is intended for use by students of the DoD acquisition process and to provoke discussions of how DoD can better integrate cost trade-offs and cost targeting into its own acquisition processes and integrated process teams. The contents of the document are based on two visits made by the authors to Ford during 1995; updates and revisions from Ford management in 1996; and other studies and contacts going back several years by the authors and others.

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